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ORIGINAL ARTICLE

CHARACTERISTICS OF METAL ALLOYS PROPERTIES FOR DENTAL CASTING AFTER THEIR REPEATED REMELTING

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ABSTRACT

The aim: To study clinical and experimental substantiation of the possibility of using cobalt-chromium and nickel-chromium alloys after repeated remelting for non-removable one-piece prosthetics.

Materials and methods: Experimental studies of Remanium GM 700 and Remanium CSe dental alloys have been carried out. To study the physical and mechanical properties of alloys, samples were obtained by sequential six-fold remelting in a Tiegelschleuder TS casting dental unit manufactured by Degussa. All samples were subjected to chemical analysis and metallographic studies by methods generally known in metallurgy, which included studies of microhardness, elasticity, tensile deformation, bending deformation and alloy structure after repeated remelting.

Results: Thus, the obtained results of the chemical, physicomechanical and structural properties of the remelts indicate that the Remanium GM 700 and Remanium CSe alloys can be reused many times for the manufacture of one-piece orthopedic structures in that they are identical with certified alloys.

Conclusions: In terms of structure, qualitative and quantitative composition of elements, physical and technological properties, the Remanium GM 700 and Remanium CSe alloys have been repeatedly remelted meet the requirements of materials used in biologically active environments of the patient's body. High-quality and cost-effective remelted multiple times Remanium GM 700 and Remanium CSe alloys can be recommended for use in practical prosthetic dentistry six times.

KEY WORDS: metal alloy, casting, cobalt-chromium alloy, nickel-chromium alloy

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INTRODUCTION

At the present stage of its development, dental materials science has a wide range of various materials, the properties of which allow their use in certain clinical cases. Undoubtedly, orthopedic constructions made of the latest materials using advanced technologies actively compete with previously known materials which are due to the requirements for modern orthopedic treatment, taking into account the functional properties of prostheses, their durability, aesthetics, biocompatibility and cost effectiveness. However, certain clinical cases dictate the choice of material for the manufacture of orthopedic structures, based on its properties, which cannot always be achieved using modern materials. One of such constructions is one-piece prostheses [1-4].

The demand of the population for prosthetics is quite high, and the demand for the manufacture of fixed structures of dentures reaches 80% of the total number of patients who have applied for prosthetics [5-7].

Changes in the main indicators of the physical and mechanical properties of metal alloys during their operation can lead to galvanic disorders, toxic effects, allergic reactions, and changes in the reactivity of the body. In addition, the quality of alloys also depends on the conditions of their melting and casting – in open induction or vacuum furnaces [8].

Due to thelarge number of cobalt-chromium and nickel-chromium alloys names most of which, as a rule, have a high cost as well as a large a mount of non-recyclable waste from the production oforthopedic structures and based on the principles of economy and rational use of resources it is advisable to use such alloys repeatedly.

Research focused on solving this issue showed that the double vacuum casting method provides increased purity of alloys and allows the use of up to 50% remelting [9, 10].

In the available literary sources, there is a small amount of research on the physicochemical and technological characteristics of these alloys by their multiple remelting [11]. Thus, this issue is relevant and requires a comprehensive study.

THE AIM

The aim of the study is a clinical and experimental substantiation of the possibility of using cobalt-chromium and nickel-chromium alloys after repeated remelting for non-removable one-piece prosthetics.

MATERIALS AND METHODS

Experimental studies of two dental alloys used for the manufacture of fixed solid structures of dentures have been carried out. All standardized metal alloys are conditionally divided into two groups. Samples of alloys Remanium GM 700 (group I) and Remanium CSe (group II) served as controls. The cobalt-chromium alloy Remanium GM 700 was introduced into the III experimental group, which was successively remelted six times by the method of vacuum remelting in the mode specified by the manufacturer "Dentaurum" (Germany), in our modification. In the IV experimental group was introduced alloy Remanium CSe, which passed a similar path of study.

To study the physical and mechanical properties of alloys, samples were obtained by sequential six-fold remelting in a dental casting unit Tiegelschleuder TS from Degussa. The remelting took place according to the instructions for these alloys in ceramic crucibles. Melting point 1410°C and holding time 10 minutes. After melting and holding at an appropriate temperature for 1 min. the melt was poured into a casting flask made of Castorit-Super C material and cooled naturally to room temperature.

For each subsequent remelting, the remnants of the re-alloy were carefully cleaned from the molding sand by the traditional method and an equal part of the alloys of the certificate supply was added.

The next remeltswere carried out at temperatures of 1500°, 1600°, 1700°, 1800°, 1030°, 870°, and 36 heats were performed in 110 seconds. and 36 swimming trunks – for 220 sec. each one. The temperature drop from the furnace crucible to the mold was 100°C.

Then all samples were subjected to heat treatment under the following conditions: 36 samples of Remanium GM 700 and Remanium CSe, cast in 110 seconds; chilled gradually. The same number of samples was cooled in 10% saline solution at room temperature. Samples cast in 220 seconds were cooled by a similar method. The temperature was determined with a thermoelectric thermometer.

The cast metal was processed in a sandblasting machine and the first heat treatment was carried out at t=1000°C for 5 minutes, then the oxide film was removed with a sandblasting machine, again subjected to heat treatment at t=1000°C for 5 minutes and so 2-3 times to the formation of a high-quality oxidizing gray films.

Three types of samples were prepared from each remelting: 1 – for the study of micro hardness – 10 samples in the form of a 10x10x2 mm plate; 2 – for measuring the modulus of elasticity – 10 samples in the form of a cylinder 36 mm long and 3 mm in diameter; 3-10 samples for stretching in the form of double-sided blades with the size of the working part 25x5x0. 4 mm.

For the study, the samples were obtained in the form of plates with a thickness of 0.4 mm, the surface of which was subjected to sandblasting with alumina with a dispersion of 50 μm and treated with sandpaper on a glass plate with abrasive powder, degreased with steam at 160°C.

All samples were subjected to chemical analysis and metallographic research according to well-known methods in metallurgy.

To study the microhardness (in MPa), the samples of the studied alloys were additionally ground and polished on suede with diamond paste to a mirror shine. The microhardness was investigated on a PMT-3 device at various loads on the indenter (10, 20, 50, 100 g). On each of the test samples, 100 prints were obtained and the average value was found.

The modulus of elasticity was measured by the acoustic method of a double vibrator at a resonant frequency of 73 kHz, at the amplitude of the sound wave $\Sigma=10^{-7}$.

Tensile deformation was performed in a bursting installation MRC-1 with a strain rate of 0,2 mm/min on samples of a dumbbell-shaped form with the sizes of a working part of 25x5x0,4 mm. In this case, 10 samples were examined in the initial state after casting, 10 samples of the alloy after each remelting.

The obtained deformation curves were used to determine the conditional boundary of yield $\delta_{0,2}$, ultimate strength $\delta_{elasticity}$ and the maximum deformation before failure Σ_{max}.

Bending deformation was also performed in the installation of MRC-1 with a prefix for four-point bending. For this purpose, samples of alloys with a size of 40x5x0,5 mm from different remelting groups were used.

The structure of the alloy was studied on a JSM-820 scanning electron microscope with a Link AN 10/85 S X-ray microanalysis system by plotting element distribution maps using the corresponding X-ray lines. The studies were carried out on cross-sectional sections of the samples, in this case, both the chemical and phase composition were studied, and fractographic studies of the fracture surfaces of the samples after tensile deformation were carried out. X-ray structural studies were performed on a diffractometer DRON-3 M.

The surface morphology of the samples destroyed after deformation by tension was also investigated in a JSM-820 scanning microscope in both absorbed and reflected electrons.

Quantitative indicators of physical and mechanical properties of metal alloys were processed by the method of variation statistics according to Student-Fisher. Statistical processing of the obtained results was performed using an integrated application package "Microsoft Excel" [12, 13].

RESULTS

To study the microhardness index, the mechanical properties and structure of the dental alloys Remanium GM 700 and Remanium CSe manufactured by the Dentaurum Company were studied after six successive remelts.

Table I shows the average data of measurements of the microhardness of the investigated alloy Remanium GM 700 and Remanium CSe at 20 points both in the state of delivery and after each of six successive remelts at various loads on the indenter.

An analysis of microhardness measurements of the Remanium CSe alloy shows that two tendencies are well traced – a decrease in microhardness for an increase in the load on the indenter and a decrease in microhardness during successive remeltings. Both of these tendencies took place in the study of the Remanium GM 700 alloy

Table I. The value of microhardness (Hv, in GPa) of samples (n=10) of the alloy Remanium GM 700 and Remanium CSe at different loads

	Remanium GM 700				Remanium CSe			
Load Sample	10 gr	20 g	50 g	100 g	10 g	20 g	50 g	100 g
Primarysample	7,9	7,9	6,8	6,4	4,5	5,02	4,89	4,65
I remelting	6,7	5,5	5,8	5,6	3,22	3,05	2,98	2,75
II remelting	6,6	5,8	5,2	5,7	2,93	2,92	2,74	2,52
III remelting	5,9	5,1	5,4	4,9	2,58	2,87	2,8	2,82
IV remelting	4,8	5,4	4,9	4,8	3,0	3,08	3,0	2,79
V remelting	4,9	5,1	4,6	4,6	2,72	2,63	2,54	2,45
VI remelting	4,7	4,7	4,3	4,5	2,6	2,20	2,45	2,39

Table II. The modulus of elasticity of samples of alloys Remanium GM 700 and Remanium CSe (E, GPa)

	Remanium GM 700	Remanium CSe
Passport data	230	170
I remelting	231	188
II remelting	234	195
III remelting	220	190
IV remelting	215	196
V remelting	220	193
VI remelting	223	192

samples, moreover, because the first of them is typical for all materials.

According to the second tendency, for the samples of the RemaniumC Se alloy, a decrease in the microhardness is observed already after the first remelting, while for the samples of the Remanium GM 700 alloy it is less pronounced.

Table II shows the values of the modulus of elasticity for samples of the alloy Remanium GM 700 and Remanium CSe after each remelting in comparison with the passport data.

Within the experimental error, it is clearly seen that the value of the elastic modulus remains constant after all six remelts of the Remanium GM 700 alloy and corresponds to the passport data. In remelted samples of Remanium CSe alloy, the modulus of elasticity is higher than in the passport data, which cannot be explained by accidental error.

The most significant difference in comparison with the passport data was observed in the value of the maximum deformation before damage: in the samples studied by us, Σ_{max} did not exceed 1%, while the manufacturer guarantees this value at the level of 4%. Regarding the values of $\delta_{0,2}$, and $\delta_{elasticity}$, for the initial remelting there is a good coincidence of measured and passport data.

At the same time, after repeated remelting, another type of deformation curves is observed, which is characterized by a much earlier damage, mainly in the area of elastic deformation, which indicates the brittle nature of the damage. The latter is also confirmed by the appearance of the damaged surface. In this case, the ultimate strength of such samples $\delta_{elasticity}$ can be several times lower in comparison with the ultimate strength for curves of the first type $\delta_{elasticity}$.

Of particular interest is the relationship between the indicated types of deformation curves and the nature of damage – if only the first type of curves is characteristic of the initial remelting, then starting from the third remelting, the second type appears, and it begins to prevail before the sixth remelting.

The data of the conditional yield point of $\delta_{0,2}$ forsampels having deformation curves of the first type within the experimental data does not depend on the number of remelts and quite accurately coincides with the passport value of 740 MPa.

Ultimate strength $\delta_{elasticity}$ tends to decrease as the number of remelts increases and does not reach the passport value of 960 MPa, which is primarily associated with the above-mentioned marked decrease in the maximum deformation to damage. These values of $\delta_{elasticity}$ (for curves of the second type) indicate a catastrophic decrease in the strength of these samples.

Thus, the presented results of a comprehensive study of the mechanical characteristics of the dental alloy Remanium GM 700 indicate a tendency for these characteristics to decrease as the number of remelts increases. At the same time, some samples after the third remelting and further have a brittle behavior with a catastrophic decrease in strength characteristics, and its probability increases significantly as the number of remelts increases.

The deformation curves of the Remanium CSe alloy sampels after each remelting have a standard parabolic form. Three parameters were studied on these curves: the conditional yield strength of $\delta_{0,2}$, the yield strength of δ_{max}, the maximum deformation to damage Σ_{max}.

In terms of the Σ_{max} value, as in the Remanium GM 700 alloy, there was a significant decrease in this value in comparison with the passport data (15%). According to our data, Σ_{max} does not exceed 3%. The conditional yield strength systematically exceeds the passport data, while the yield strength is partially inferior to the passport value.

Thus, the mechanical properties of the alloy Remanium CSe at six consecutive remelts practically do not show degradation. There is only a slight decrease in the individual studied characteristics (Hv, $\delta_{max,}$ Σ_{max}) after the first remelting, while other characteristics (E, $\delta_{0,2}$) even exceed the passport data after all remelts.

The data obtained using X-ray microanalysis averaged over an area of 500x500 μm^2 data on the content of the three main alloy elements after each of the successive remelts suggests that the composition of the Remanium GM 700 alloy has not changed and corresponds to its passport data after all remelts.

However, the analysis of local data indicates a significant inhomogeneity of the composition in the remelted samples, which also grows as the number of remelts increases. The indicated inhomogeneity, on the one hand, is due to the fact that the alloy is two-phase. At the same time, if in the initial samples the second phase is so small that it was possible to recognize it only with the help of X-ray structural analysis, then in the remelted samples the sizes of the inclusions of the second phase are higher, and it was possible to find it on the electron microscopic images of the surface of thin sections of all remelted samples.

In our opinion, the structural differences between the remelted alloy samples and the primary ones found by us cannot make significant changes in their mechanical properties which were proved in the course of the study.

A comparative study of the fracture surface of the samples after plastic and brittle damage has shown that for brittle damage rather large (~ 50 μm) grains are formed on the fracture surface, embedded in the amorphized matrix. The composition of these inclusions, determined by X-ray microanalysis, corresponds to silicon oxide with carbon impurities.

It is known that silicon and carbon in small amounts are included in the alloy. In addition, silicon and carbon are contained both in the material of the crucibles, where the initial alloy is melted, and in the material from which the molds are made, where the remelt is poured for solidification.

All this allows us to assume that silicon and carbon, which are part of the alloy, and obtained additionally from the outside, are localized in certain places of remelting, making these places very low-strength due to the high brittleness of oxides and insufficient connection of inclusions with the matrix.

The number of samples with a high local concentration of these inclusions increases with successive remelting, which leads to an increase in the number of brittle damage to the samples during stretching.

Changing the remelting mode (holding time in the molten state, additional movement of the melt, vacuum remelting, addition of a certified alloy to the remainders during remelting) made it possible to avoid these negative phenomena, which made it possible to more efficiently reuse the Remanium GM 700 alloy in orthopedic structures.

The results obtained by X-ray microanalysis for the content of the three main elements (Ni, Cr, Mo) of the alloy after each remelting showed that repeated remelting does not lead to significant changes in the content of the main elements. However, in the Remanium CSe alloy, a rather high compositional inhomogeneity is observed. As evidenced by scanning electron microscopic observations and X-ray diffraction analysis, the research alloy is two-phase, and the dimensions of the second phase are extremely small, although they increase with the number of remelts.

X-ray microanalysis of the composition of the alloy on the surfaces of the damage showed that in contrast to the alloy Remanium GM 700 in the experimental alloy Remanium CSe found no oxides and carbides, which lead to the fragility of this alloy. The revealed circumstance fully explains the fact that in the process of six-fold remelting of the Remanium CSe alloy, a catastrophic decrease in its strength characteristics is not observed.

Obtained results indicate that Remanium CSe alloy can be reused repeatedly for the manufacture of one-piece orthopedic structures, and for Remanium GM 700 alloy can also be recycled, but for this the alloy does not need to be overheated.

Due to the fact that there are a large number of alloys of different types and with different numbers of components, as well as different manufacturers, we consider it appropriate to sort the residues of alloys by type and manufacturer in order to carry out full recycling.

Thus, the obtained results of the chemical, physic-mechanical and structural properties of the remelts indicate that the Remanium GM 700 and Remanium CSe alloys can be reused many times for the manufacture of one-piece orthopedic structures in that they are identical with certified alloys.

DISCUSSION

To solve these problems, laboratory and experimental studies were conducted, which consisted in a comparative assessment of the physical and mechanical properties and structure of the experimental alloys after their repeated remelting.

The analysis of local data indicates a significant inhomogeneity of the composition in the remelted samples, which increases with an increase in the number of remelts. This inhomogeneity, on the one hand, is due to the fact that the investigated alloys are two-phase.

Studying the physical and mechanical properties of research metal alloys, a structural analysis of prototypes on the fracture surface was carried out. The results of the study showed that the Co-based alloy (Remanium GM 700) has a higher microhardness in the cast and heat-treated state, and, in contrast to the Ni-based alloy (Remanium CSe), heat treatment of this alloy increases its microhardness. This can be explained by the fact that after casting Remanium GM 700 we found large (5-10 μm) inclusions of the second phase, enriched with chromium and molybdenum, and the microhardness of this phase is much higher than the microhardness of the matrix [14-16]. According to our data, heat treatment partially dissolves the second phase in the matrix, which causes the transition of Cr and Mo atoms into it and increases the microhardness.

The structural differences of the remelted samples from the initial ones revealed by us cannot make significant changes in their mechanical properties, which have been proved.

The selection of the optimal alloying degree of alloys by using microadditives from standardized alloys made it possible to obtain alloys with sufficient strength, ductility, and fluidity that meet international standards and provide the functional properties of non-removable solid cast structures of dentures, and reduce the consumption of alloys.

CONCLUSIONS

The study shows the possibilities of using the alloys Remanium GM 700 and Remanium CSe after repeated remelting for the manufacture of non-removable one-piece structures of dentures.

Based on laboratory and experimental research data, a method of alloy recirculation has been developed. It can be argued that the method of six-fold vacuum remelting provides an increased purity of the Remanium GM 700 and Remanium CSe alloys and allows the use of remelting with the addition of alloying components many times.

In terms of structure, qualitative and quantitative composition of elements, physical and technological properties of repeatedly remelted alloys Remanium GM 700 and Remanium CSe meet the requirements for materials used in biologically active environments of patients.

High-quality and cost-effective reusable vacuum remelted alloys Remanium GM 700 and Remanium CSe can be recommended for use in practical orthopedic dentistry six times.

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Conflict of interest:

The Authors declare no conflict of interest

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